CLAIMS

What is claimed is:

1. A data communications link, comprising:

an optical source comprising a single transverse mode, multiple longitudinal mode laser device;

an optical receiver separated from said optical source by less than 10 km; and

a single mode optical fiber for transmitting an optical signal generated by said optical source to said optical receiver;

the presence of multiple longitudinal modes facilitating increased single transverse mode output power and thermal stability in the optical source, and said data communications link achieving a data throughput performance substantially higher than 1 Gbps-km.

2. The data communications link of claim 1, wherein said optical signal generated by said optical source comprises a first longitudinal mode at a wavelength greater than 1200 nm.

3. The data communications link of claim 2, wherein said optical signal generated by said optical source further comprises a second longitudinal mode having a power that is greater than –20 dB with respect to a power of said first longitudinal mode.

4. The data communications link of claim 2, wherein said optical signal generated by said optical source further comprises a third longitudinal mode having a power that is greater than –20 dB with respect to a power of said first longitudinal mode.

5. The data communications link of claim 2, wherein said first longitudinal mode lies between 1200 nm and 1570 nm, and wherein said optical receiver is sufficiently close to said optical source such that attenuation and chromatic dispersion of the optical signal between said optical source and said optical receiver are nonlimiting factors in designing the data communications link.

6. The data communications link of claim 5, wherein said optical receiver is separated from said optical source by less than 1 km, whereby attenuation and chromatic dispersion of the optical signal between said optical source and said optical receiver are negligible factors in designing the data communications link.

7. The data communications link of claim 1, said laser device comprising an active region having a gain spectrum, said laser device further comprising an optical cavity defining a plurality of possible longitudinal modes separated by a longitudinal mode spacing, wherein said gain spectrum has a width greater than two times said longitudinal mode spacing.

8. The data communications link of claim 7, wherein said gain spectrum has a width greater than five times said longitudinal mode spacing.

9. The data communications link of claim 7, further comprising:

at least one additional optical source also comprising a single transverse mode, multiple longitudinal mode laser device, wherein said optical sources generate a plurality of optical signals at different wavelengths;

a wavelength division multiplexing (WDM) multiplexer positioned between said optical sources and said single mode optical fiber for generating a wavelength division multiplexed (WDM) optical signal from said plurality of optical signals;

a WDM demultiplexer positioned to receive and separate said WDM optical signal into said plurality of optical signals; and

at least one additional optical receiver corresponding to said at least one additional optical source.

10. The data communications link of claim 9, wherein said WDM optical signal comprises at least four channels at wavelengths greater than 1200 nm, said channels being spaced apart by at least 20 nm.

11. The data communications link of claim 10, wherein at least one of said optical channels lies in a wavelength range corresponding to an OH absorption peak of the single mode optical fiber.

12. The data communications link of claim 2, wherein said laser device comprises a vertical cavity surface emitting laser (VCSEL), said VCSEL having an effective cavity length that is at least three times said wavelength of said first longitudinal mode.

13. The data communications link of claim 12, wherein said effective cavity length is at least ten times said wavelength of said first longitudinal mode.

14. The data communications link of claim 12, wherein said effective cavity length is at least fifty times said wavelength of said first longitudinal mode.

15. The data communications link of claim 12, said VCSEL comprising a first distributed Bragg reflector (DBR), a second DBR, and a vertical cavity therebetween, wherein said first DBR comprises an amorphous material.

16. The data communications link of claim 15, wherein said amorphous material is a dielectric material.

17. The data communications link of claim 15, said VCSEL further comprising a lateral overgrowth layer between said first and second DBRs.

18. The data communications link of claim 17, wherein said lateral overgrowth layer has a length that is at least fifty percent of said effective cavity length.

19. The data communications link of claim 18, said VCSEL comprising a substrate upon which said first DBR is deposited in a manner that exposes a portion of said substrate after said deposition, said lateral overgrowth layer being formed by epitaxially growing an overgrowth material over said substrate such that said overgrowth material converges over

said first DBR and achieves sufficient flatness for epitaxial growth of subsequent vertical cavity layers thereon.

20. The data communications link of claim 19, wherein said substrate comprises InP, and wherein said lateral overgrowth material comprises InP.

21. The data communications link of claim 19, said subsequent vertical cavity layers including active region layers, wherein said VCSEL is fabricated according to a single-growth process not requiring a wafer bonding step.

22. The data communications link of claim 19, wherein said first DBR is curved to form a concave shape with respect to the vertical cavity such that said vertical cavity forms a stable resonant cavity.

23. The data communications link of claim 19, wherein said first DBR is curved to form a convex shape with respect to the vertical cavity such that said vertical cavity forms an unstable resonant cavity.

24. An optical communications link, comprising:

a single transverse mode, multiple longitudinal mode optical source;

an optical receiver; and

a single mode optical fiber for transmitting an optical signal generated by said optical source to said optical receiver;

said optical receiver being sufficiently close to said optical source to effectively make attenuation and chromatic dispersion of the optical signal between said optical source and said optical receiver nonlimiting factors in designing the optical communications link.

25. The optical communications link of claim 24, wherein said optical receiver is less than 10 km from said optical source.

26. The optical communications link of claim 25, wherein said optical signal generated by said optical source comprises a dominant longitudinal mode and at least one side longitudinal mode, and wherein said at least one side longitudinal mode has a power level that is greater than –20 dB with respect to a power level of the dominant longitudinal mode.

27. The optical communications link of claim 26, wherein said dominant longitudinal mode is at a wavelength greater than 1200 nm.

28. The optical communications link of claim 24, wherein said optical source comprises a vertical cavity surface emitting laser (VCSEL), said VCSEL having an effective cavity length that is at least three times said wavelength of said dominant longitudinal mode.

29. The optical communications link of claim 28, wherein said effective cavity length is at least ten times said wavelength of said dominant longitudinal mode, whereby said longitudinal modes are spaced apart by less than 30 nm.

30. The optical communications link of claim 29, wherein at least fifty percent of said effective cavity length is occupied by a spacer layer formed by lateral overgrowth of an epitaxial material over an amorphous material.

31. The optical communications link of claim 30, said VCSEL comprising a distributed Bragg reflector (DBR) defining one end of a vertical cavity thereof, wherein said DBR comprises said amorphous material.

32. The optical communications link of claim 31, said VCSEL comprising a substrate upon which said DBR is deposited and from which said spacer layer is laterally overgrown over said DBR.

33. The optical communications link of claim 32, wherein said substrate comprises InP, and wherein said DBR comprises a dielectric material.

34. The optical communications link of claim 32, wherein said DBR is at least partially buried in said substrate prior to said lateral overgrowth of said spacer layer to facilitate flatness of a top surface of said spacer layer prior to epitaxial growth of subsequent material layers thereon.

35. The optical communications link of claim 32, wherein said DBR is curved to form a concave shape with respect to said vertical cavity such that said vertical cavity forms a stable resonant cavity.

36. The optical communications link of claim 32, wherein said DBR is curved to form a convex shape with respect to said vertical cavity such that said vertical cavity forms an unstable resonant cavity.

37. An apparatus for facilitating data communications between a source location and a receiver location, comprising:

a vertical cavity surface emitting laser (VCSEL) at the source location, said VCSEL being designed to operate in a single transverse mode, multiple longitudinal mode manner; and

a single mode optical fiber for transmitting an optical signal generated by said VCSEL to said receiver location.

38. The apparatus of claim 37, said VCSEL comprising a vertical cavity having an effective cavity length and an active region having a gain spectrum, wherein said effective cavity length is sufficient to cause at least two possible longitudinal modes to fall within said gain spectrum.

39. The apparatus of claim 38, wherein said effective cavity length is greater than five times an operating wavelength of said VCSEL.

40. The apparatus of claim 39, wherein said VCSEL comprises a laterally overgrown spacer layer occupying at least fifty percent of said effective cavity length.

41. An apparatus for facilitating data communications between a source location and a receiver location separated by a distance for which a single-mode fiber causes less than 15 dB of attenuation and less than 200 ps/nm of chromatic dispersion, comprising:

a vertical cavity surface emitting laser (VCSEL) at the source location, said VCSEL being designed to operate in a single transverse mode; and

a single mode optical fiber for transmitting an optical signal generated by said VCSEL to said receiver location.

42. The apparatus of claim 41, said VCSEL comprising a vertical cavity having an effective cavity length and an active region having a gain spectrum, wherein said effective cavity length is sufficient to cause at least two possible longitudinal modes to fall within said gain spectrum, and wherein said VCSEL emits at least two longitudinal modes comprising a dominant longitudinal mode and a side longitudinal mode, said side longitudinal mode being at least –20 dB with respect to said dominant longitudinal mode.

43. The apparatus of claim 42, wherein said effective cavity length is greater than five times a wavelength of said dominant longitudinal mode.

44. The apparatus of claim 43, wherein said VCSEL comprises a laterally overgrown spacer layer occupying at least fifty percent of said effective cavity length.

45. An apparatus for facilitating data communications between a source location and a receiver location, comprising:

a plurality of vertical cavity surface emitting lasers (VCSELs) at the source location, each VCSEL emitting an optical signal corresponding to a different source channel, each VCSEL being designed to operate in a single transverse mode, multiple longitudinal mode manner;

a wavelength division multiplexing (WDM) device for combining said plurality of optical signals into a single wavelength division multiplexed (WDM) signal; and

a single mode optical fiber for transmitting said WDM signal to said receiver location.

46. The apparatus of claim 45, each of said plurality of VCSELs comprising a vertical cavity having an effective cavity length and an active region having a gain spectrum, wherein said effective cavity length is sufficient to cause at least two possible longitudinal modes to fall within said gain spectrum, and wherein said VCSEL emits at least two longitudinal modes including a dominant longitudinal mode and a side longitudinal mode, said side longitudinal mode being at least –20 dB with respect to said dominant longitudinal mode.

47. The apparatus of claim 46, wherein said effective cavity length is greater than five times a wavelength of said dominant longitudinal mode.

48. The apparatus of claim 47, wherein said VCSEL comprises a laterally overgrown spacer layer occupying at least fifty percent of said effective cavity length.

49. The apparatus of claim 46, wherein said effective cavity length for each of said plurality of VCSELs is greater than ten times a wavelength of said dominant longitudinal mode for that VCSEL, wherein said side longitudinal mode for each of said plurality of VCSELs is within 30 nm of said dominant longitudinal mode for that VCSEL, and wherein said WDM signal comprises at least two channels at wavelengths greater than 1200 nm that are spaced apart by at least 60 nm.

50. The apparatus of claim 49, wherein said WDM signal comprises at least four channels at wavelengths greater than 1200 nm that are spaced apart by at least 60 nm.

51. A vertical cavity surface emitting laser (VCSEL), comprising a first distributed Bragg reflector (DBR) and a second DBR defining a vertical cavity therebetween having

an effective vertical cavity length, wherein said effective vertical cavity length is at least ten times an operating wavelength of the VCSEL.

52. The VCSEL of claim 51, wherein said effective vertical cavity length is at least fifty times said operating wavelength of the VCSEL.

53. The VCSEL of claim 51, wherein said first DBR is curved such that said vertical cavity forms a stable resonant cavity.

54. The VCSEL of claim 51, wherein said first DBR is curved such that said vertical cavity forms an unstable resonant cavity.

55. The VCSEL of claim 51, wherein said first DBR comprises an amorphous material, the VCSEL further comprising:

a first layer upon which said first DBR is formed, said first layer comprising a material capable of accommodating epitaxial growth;

a second layer epitaxially grown from said first layer in a manner that laterally covers said first DBR; and

a third layer epitaxially grown upon said second layer.

56. The VCSEL of claim 55, wherein said first DBR is at least partially buried in a trench formed in said first layer.

57. The VCSEL of claim 56, said trench being concave in shape with respect to the vertical cavity, said DBR being conformally deposited thereon, wherein said vertical cavity forms a stable resonant cavity.

58. The VCSEL of claim 57, said operating wavelength being greater than 1200 nm, wherein said first and second layers comprise InP.

59. The VCSEL of claim 58, wherein said amorphous material is a dielectric material.

60. The VCSEL of claim 55, wherein said second layer occupies at least fifty percent of the effective cavity length of said vertical cavity.

61. A vertical cavity surface emitting laser (VCSEL), comprising a first distributed Bragg reflector (DBR) and a second DBR defining a vertical cavity therebetween, wherein said first DBR is curved such that said vertical cavity forms a stable resonant cavity.

62. The VCSEL of claim 61, further comprising:

a first layer upon which said first DBR is formed, said DBR comprising an amorphous material, said first layer comprising an epitaxial material; and

a lateral overgrowth layer that is epitaxially grown from said first layer over said first DBR.

63. The VCSEL of claim 62, further comprising an active region having a gain spectrum lying above 1200 nm, wherein an effective length of said vertical cavity is sufficiently long such that at least two longitudinal modes fall within said gain spectrum, and wherein said VCSEL emits a dominant longitudinal mode and a side longitudinal mode having a power level not less than –20 dB of a power level of the dominant longitudinal mode.

64. The VCSEL of claim 63, wherein said VCSEL is configured and dimensioned to operate in a single transverse mode, and wherein said lateral overgrowth layer occupies at least fifty percent of the effective length of said vertical cavity.

65. The VCSEL of claim 64, wherein said first DBR comprises a dielectric material.

66. A vertical cavity surface emitting laser (VCSEL), comprising a first distributed Bragg reflector (DBR) and a second DBR defining a vertical cavity therebetween, wherein said first DBR is curved such that said vertical cavity forms an unstable resonant cavity.

67. The VCSEL of claim 66, further comprising:

a first layer upon which said first DBR is formed, said DBR comprising an amorphous material, said first layer comprising an epitaxial material; and

a lateral overgrowth layer that is epitaxially grown from said first layer over said first DBR.

68. The VCSEL of claim 67, further comprising an active region having a gain spectrum lying above 1200 nm, wherein an effective length of said vertical cavity is sufficient such that at least two longitudinal modes fall within said gain spectrum, and wherein said VCSEL emits a dominant longitudinal mode and a side longitudinal mode having a power level not less than –20 dB of a power level of the dominant longitudinal mode.

69. The VCSEL of claim 68, wherein said VCSEL is configured and dimensioned to operate in a single transverse mode, and wherein said lateral overgrowth layer occupies at least fifty percent of the effective length of said vertical cavity.

70. The VCSEL of claim 69, wherein said first DBR comprises a dielectric material.

71. A single transverse mode, multiple longitudinal mode VCSEL configured to operate at a wavelength above 1200 nm, comprising:

a first distributed Bragg reflector (DBR) and a second DBR defining a vertical cavity therebetween having an effective cavity length;

a spacer layer lying within said vertical cavity, said spacer layer occupying more than fifty percent of the effective cavity length; and

an active region lying in said vertical cavity, said active region having a gain spectrum lying above 1200 nm;

wherein said spacer layer is sufficiently thick for said vertical cavity to accommodate at least two longitudinal modes within said gain spectrum.

72. The single transverse mode, multiple longitudinal mode VCSEL of claim 71, wherein said active region comprises layers consistent with a InGaAsP or AlInGaAs material system.

73. The single transverse mode, multiple longitudinal mode VCSEL of claim 71, wherein said gain spectrum has an effective width of at least 60 nm, and wherein said effective cavity length is greater than ten times the operating wavelength.

74. The single transverse mode, multiple longitudinal mode VCSEL of claim 73, wherein a dominant longitudinal mode and at least one side longitudinal mode are emitted by said VCSEL, said side longitudinal modes having a power that is at least –20 dB of the power of said dominant longitudinal mode.

75. The single transverse mode, multiple longitudinal mode VCSEL of claim 71, wherein said first DBR comprises an amorphous material, and wherein said spacer layer is laterally overgrown on said first DBR.

76. The single transverse mode, multiple longitudinal mode VCSEL of claim 75, further comprising an InP substrate, wherein said first DBR is deposited on said InP substrate, and wherein said spacer layer comprises InP.

77. The single transverse mode, multiple longitudinal mode VCSEL of claim 75, wherein said first DBR comprises a dielectric material.

78. The single transverse mode, multiple longitudinal mode VCSEL of claim 71, wherein said first DBR is curved such that said vertical cavity forms a stable resonant cavity.

79. The single transverse mode, multiple longitudinal mode VCSEL of claim 71, wherein said first DBR is curved such that said vertical cavity forms an unstable resonant cavity.

80. A method for fabricating a vertical cavity surface emitting laser (VCSEL) having a concave reflective surface therein, comprising the steps of:

forming a concave well in a substrate;

forming a first reflective element conformal to said concave well;

forming a spacer layer immediately above said first reflective element, said spacer layer being optically inactive with respect to an electric current therethrough;

forming active region layers above said spacer layer, said active region being optically responsive to an electric current therethrough; and

forming a second reflective element above said vertical cavity layers.

81. The method of claim 80, wherein the forming of said first reflective element comprises forming a distributed Bragg reflector (DBR) comprising an amorphous material, wherein said forming a well comprises forming the well in a substrate comprising a first material accommodating epitaxial growth, and wherein said step of forming a spacer layer comprises of epitaxially and laterally overgrowing a second material from said substrate over said DBR until a top surface of the spacer layer is substantially flat.

82. The method of claim 81, wherein said first and second materials are InP, and wherein said DBR comprises a dielectric material.

83. The method of claim 80, said step of forming a concave well comprising the steps of:

sequentially etching patterns of different lateral sizes into said substrate until an intermediate well is formed having stair-like structures on its surface; and

heating the substrate at very high temperatures until a mass transportation effect causes the stair-like structures to substantially smooth out.

84. The method of claim 83, further comprising the step of conformally depositing the DBR in the concave well.

85. A method for fabricating a vertical cavity surface emitting laser (VCSEL) having a convex reflective surface therein, comprising the steps of:

forming a substrate having a convex structure thereon;

forming a first reflective element conformal to said convex structure;

forming a spacer layer immediately above said first reflective element, said spacer layer being optically inactive with respect to an electric current therethrough;

forming active region layers above said spacer layer, said active region being optically responsive to an electric current therethrough; and

forming a second reflective element above said vertical cavity layers.

86. The method of claim 85, wherein the forming of said first reflective element comprises forming a distributed Bragg reflector (DBR) comprising an amorphous material, wherein said forming a substrate comprises forming a substrate that includes a first material capable of accommodating epitaxial growth, and wherein said forming of a spacer layer comprises epitaxially and laterally overgrowing a second material from said substrate over said DBR until a top surface of the spacer layer is substantially flat.

87. The method of claim 86, wherein said first and second materials are InP, and wherein said DBR comprises a dielectric material.

88. The method of claim 86, said forming a substrate having a convex structure thereon comprising the steps of:

forming a photoresist layer over a lateral portion of the substrate corresponding to the convex structure;

heating the substrate until said photoresist layer melts and reflows into a convex shape corresponding to the convex structure;

dry etching the substrate including said lateral portion until the convex shape is transferred to the substrate.

89. The method of claim 88, further comprising the step of conformally depositing the DBR on the convex structure.

90. An apparatus, comprising:

a plurality of optical communication links, each optical communications link comprising:

a single transverse mode, multiple longitudinal mode optical source;

an optical receiver; and

a single mode optical fiber for transmitting an optical signal generated by said optical source to said optical receiver;

wherein said single mode optical fibers are contained in a common multifiber cable extending from a first location containing said optical sources to a second location containing said optical receivers; and

wherein said second location is sufficiently close to said first location to effectively make attenuation and chromatic dispersion of each of said optical signals nonlimiting factors in designing its respective optical communications link.

91. The apparatus of claim 90, wherein said multifiber cable comprises a fiber optic ribbon cable.

92. The apparatus of claim 90, wherein said second location is less than 10 km from said first location.

93. An apparatus, comprising:

a plurality of WDM optical communication links, each WDM optical communications link comprising:

a plurality of optical sources, each optical source generating a component optical signal;

a multiplexer for combining the component optical signals into a WDM optical signal;

an optical fiber for transporting said WDM optical signal;

a demultiplexer for receiving said WDM optical signal and separating it back into its component optical signals; and

a plurality of optical receivers for receiving said component optical signals;

wherein said optical fibers are contained in a common multifiber cable extending from a first location containing said optical sources to a second location containing said optical receivers; and

wherein said second location is sufficiently close to said first location to effectively make attenuation and chromatic dispersion of each of said WDM optical signals nonlimiting factors in designing its respective WDM optical communications link.

94. The apparatus of claim 93, wherein each of said optical sources comprises a single transverse mode, multiple longitudinal mode VCSEL, and wherein each of said optical fibers is a single mode fiber.

95. The apparatus of claim 93, wherein said multifiber cable comprises a fiber optic ribbon cable.

96. The apparatus of claim 93, wherein said second location is less than 10 km from said first location.